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LENGTH OF THE MIXING CHAMBER OF A SUPERSONIC NOZZLE AT A ZERO NOZZLE COEFFICIENT

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Symbols

M_a	Mach number through nozzle section;
l	length of mixing chamber;
$\bar{l} = l/d_v$	relative length of mixing chamber;
d_v	diameter of effective cross-section of mixing chamber;
$\bar{f}_v = f_v/f_a$	relative area of effective cross-section of mixing chamber;
P_c	pressure in chamber;
P_0	stagnation pressure in front of nozzle;
L	length of chamber;
$\bar{L} = L/d_a$	relative length of chamber;
d_a	diameter of effective cross-section of nozzle;
f_a	area of effective cross-section of nozzle;
n_{li}	limiting degree at which it is impossible to predict outflow of jet;
$\bar{l}_0 = l_0/d_v$	relative optimal length of mixing chamber.

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ABSTRACT. Experimental investigation of the influence of the length of a cylindrical mixing chamber of a supersonic nozzle on the nozzle efficiency. The physical mechanism of maintaining vacuum in the mixing chamber is analyzed for the case where the chamber length is less than the optimal length. It is shown that the chamber length which provides maximum evacuation at a zero ejection coefficient depends solely on the Mach number at the exit section of the nozzle. An empirical relation between the optimal chamber length and the Mach number at the exit section of the nozzle is derived.

In the theory of gas ejectors the problem of the rational selection of the length of the mixing chamber is one of the basic questions determining its efficiency. Individual articles existing at this time and related to the calculation of the optimal length of the mixing chamber, for example [1, 2], give clearly overstated results in comparison with the experiment. Thus, in [2] the relative length of the mixing chamber should have a value of $\overline{l} > 12$ while in practice, on the basis of experimental data, the value $\overline{l}$ = 6-8 is most often used. /564[1]

Nearly all works related to the selection of the length of the mixing chamber pertain to the case where the coefficient of ejection is not equal to zero. There exists at the same time a large number of technical systems intended for the purpose of maintaining the constant and, as a rule, greatest possible evacuation in a certain volume. In this case the coefficient of ejection is equal to zero.

It is often necessary, under specific operational conditions, to have a mixing chamber of minimal length. It is obvious however that the optimal length of the mixing chamber should depend on the properties of the stream and the length of the free jet prior to entry into the mixing chamber. By optimal we mean here a mixing chamber with a length such that maximal evacuation is insured in the chamber at a minimal pressure in front of the basic nozzle.

In view of the fact that it is not now possible to conduct theoretical investigations on this problem as regards the process of the transformation of jet flow into flow in a channel, experimental investigations were conducted on

[1] Numbers in the margin indicate pagination in the foreign text.

the effect of the length of the mixing chamber on the efficiency of ejection for a zero ejection coefficient.

A detailed description of the experimental setup is found in [4]. A diagram of the model is illustrated in Figure 1.

The model represents a chamber of length $\overline{L}$ with interchangeable cylindrical mixing chambers of various length $\overline{l}$ and of various cross-sectional area $\overline{f}_v$ installed at the outlet. The nozzle which insures a jet of a given velocity was installed on the opposite wall of the chamber. the length of the chamber varied within the limits of $\overline{L}$ = 0-7, the length of the mixing chamber $\overline{l}$ = 0-6 and the /565
area of its cross-section $\overline{f}_v$ = 0.7-25. The values of M_a (through the section of the nozzle) were equal to 1.0, 2.02, 2.45, 2.85, and 3.37.

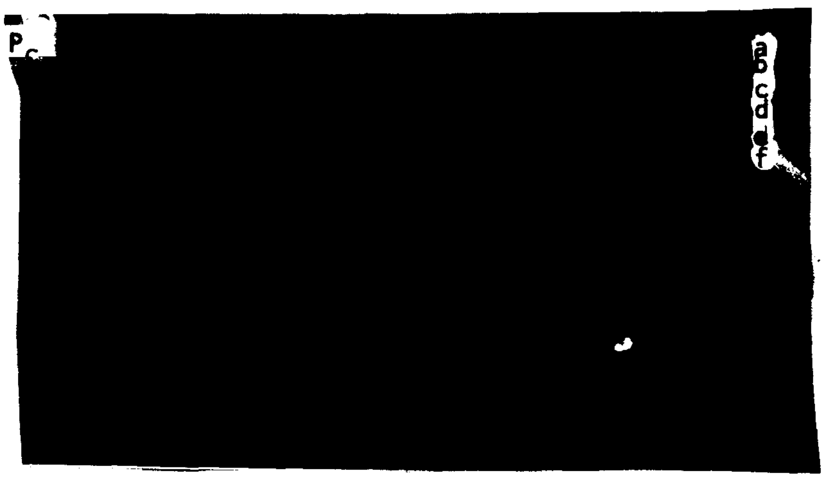

Figure 1. Dependence of Pressure in Chamber P_c on Pressure in Front of Nozzle P_0 for M_a = 2.45, L = 1.5, and $\overline{f}_v$ = 4:
a -- $\overline{l}$ = 0; b -- 0.4; c -- 1; d -- 2; e -- 4; f -- 6; 1 -- Nozzle; 2 -- Chamber; 3 -- Mixing chamber

From the experiments we obtained dependences of pressure in the chamber P_c on pressure in front of the nozzle P_0 for various values of M_a, $\overline{f}_v$, $\overline{L}$, and $\overline{l}$. The typical function $P_c = f(P_0,\overline{l})$ is shown in Figure 1. We see here that for any mixing chamber length (with the exception of some limiting length) the nature of the function $P_c = f(P_0)$ remains constant, as in the case of the absence of a mixing chamber. The mechanism for maintaining evacuation in the chamber for $\overline{l}$ = 0 was discussed in detail in [3], where it was established that evacuation in the chamber for arm I of the curve $P_c = f(P_0)$ is determined by the pressure drop in the reverse stream, which passes between the edge of the opening and the boundary of the basic jet and which compensates for the combined mass of the basic jet for length $\bar{L}$. The beginning of arm II corresponds to an unstable flow condition in the reverse stream which is related to the establishment in the reverse stream of the critical velocity and, finally, arm III corresponds to the so-called condition of the limiting degree at which it is impossible to predict the outflow of a jet n_{li}, which is characterized by a linear relationship between the pressure in the chamber P_c and the pressure in front of the nozzle P_0. The beginning of condition n_{li} is determined by the moment of contact of the edge of the outlet opening with the critical line of the stream in the boundary layer of the basic jet.

In regard to the fact that the curves of $P_c = f(P_0)$ for $\bar{l} > 0$ are similar to the analogous function for $\bar{l} = 0$ we should expect that the mechanisms for maintaining P_1 are also identical in both cases. In arms I pressure P_c is reduced with increasing $\bar{l}$ for the same P_0.

This can obviously occur only as a result of increasing velocity in the reverse stream. Actually, when we have a discharge channel of length l at the outlet from the chamber the combined mass of the basic jet and, consequently, the mass of air in the reverse stream will be determined not by the length $\bar{L}$ of the jet, but by the magnitude of $(\bar{L} + \bar{l})$, i.e. they will increase as the length of the discharge channel increases. Furthermore, it is quite obvious that the annular gap between the edge of the discharge opening and the outer boundary of the basic jet, through which air passes in the reverse stream, will diminish as the length of the channel increases because of the expansion of the jet. These factors cause the velocity in the reverse stream to increase with increasing $\bar{l}$ and the pressure in the chamber to drop when P_0 is a constant. /566

In this case, naturally, the critical condition in the reverse stream is reached when the pressure in front of the nozzle P_0 is low and when the evacuation in the chamber P_c is great. When $\bar{l} = 6$ (in the case under consideration) we note a sharp drop in pressure P_c, even for small values of P_0. This is evidence of the fact that the boundary of the jet does not immediately encompass the edge of the outlet opening.

Arm IV corresponds to the gradual transformation of the stream in the mixing chamber under the effect of increasing flow through the basic nozzle. The beginning of arm IV corresponds to the contact of the edge of the mixing chamber opening with the outer boundary of the jet in section B and its terminus corresponds to the development of the n_{li} condition, i.e. the contact of the edge of the outlet opening of the mixing chamber by the critical line of the stream in the boundary layer. This conclusion is derived from the fact that the value of n_{li} is independent of the length of the mixing chamber, as follows from Figure 1, since the arms of the curves corresponding to the n_{li} condition

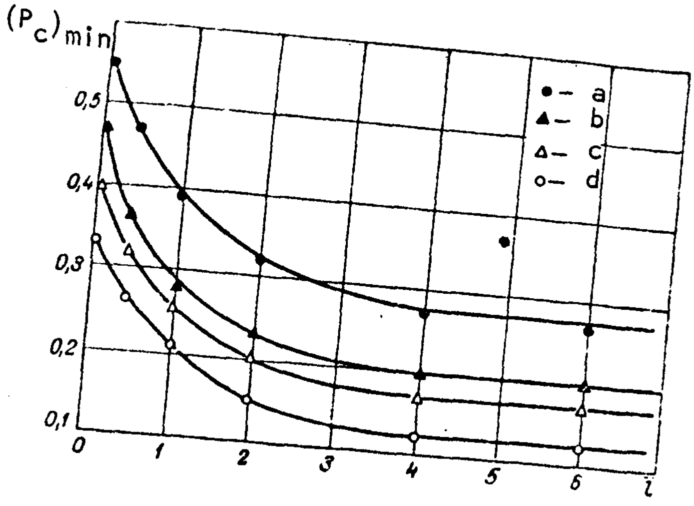

Figure 2. Dependence of Maximal Rarefaction in Chamber on Length of Mixing Chamber for $\bar{L}$ = 1.5 and M_a = 2.45:
a -- $\bar{f}_v$ = 2.25, b -- 4, c -- 5.06, d -- 9

coincide for various $\bar{l}$.

The value of the maximal evacuation in the chamber, other conditions being equal, depends on the length of the mixing chamber, increasing with an increase in the latter, as clearly seen in Figure 2. But the value of $(P_c)_{min}$, starting with some value of $\bar{l}$, ceases to depend on $\bar{l}$. This phenomenon occurs for all values of $\bar{f}_v$, M_a, and $\bar{L}$.

It thus follows that there is always some mixing chamber length which insures optimal ejection. As seen in Figure 2, for M_a = 2.45 and $\bar{L}$ = 1.5 the increase in the length of the mixing chamber $\bar{l} > 4$ is meaningless. In this case we will consider $\bar{l}$ = 4 as optimal. /567

The dependence of $\bar{l}_0$ on M_a through the section of the nozzle, the length of the chamber $\bar{L}$, and the size of the outlet opening $\bar{f}_v$ was found on the basis of a large mass of experimental data. The value of $\bar{l}_0$, as seen in Figure 3, depends only on M_a and not on $\bar{L}$ or $\bar{f}_v$. The function $\bar{l}_0 = f(M_a)$ has a linear behavior and may be approximated by the simple expression

$$\bar{l}_0 = 1.8\,M_a.$$

Thus we may make a selection of the optimal length of the mixing chamber for the conditions $\bar{l} > \bar{l}_0$, where $\bar{l}_0$ is determined by the above formula, on the basis of the studies which we have just discussed.

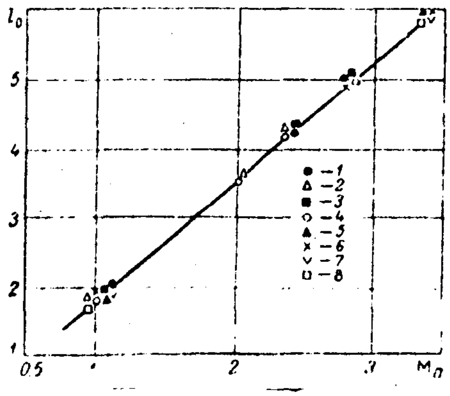

Figure 3. Dependence of the Optimal Length of Mixing Chamber on M_a:
1 -- $\bar{L} = 4.5$; $\bar{f}_v = 2.25$;
2 -- 4.5 and 4; 3 -- 1.5 and 5.06; 4 -- 1.5 and 9; 5 -- 7 and 2.25; 6 -- 7 and 4; 7 -- 7 and 5.06; 8 -- 7 and 9

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